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ORIGINAL PAPER

Fructan stability in strawberry sorbets in dependence on their source and the period of storage

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Abstract Many epidemiologic studies have shown a role of diet rich in fruits and vegetables in the prevention of several chronic diseases. Fructans are widely used in functional foods for their health-promoting and technological properties. Strawberry sorbets containing fructans could be an interesting alternative to traditional ice cream. The contents of fructan, glucose, fructose and sucrose were determined to evaluate their changes during storage of strawberry sorbets with three fructan sources: Jerusalem artichoke tubers, yacon root powder and Beneo Orafti Synergy 1. Analyses were performed immediately after product preparation, as well as during 3-month storage at −22 ± 2 °C, in the 2-week intervals. It was observed that the changes of the fructan content were insignificant during the first 2 weeks of storage in all sorbets. The decrease in fructan content was connected with the increase in the amount of glucose, fructose as well as sucrose, independently of fructan source. After 12 weeks of freezing storage, sorbet with Jerusalem artichoke tubers was characterized by the highest stability of fructans, as compared to the other products. The knowledge about the changes of carbohydrate content, especially fructans, during storage is crucial from nutritional point of view (to obtain product with the highest content of pro-healthy compounds).

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Introduction

As consumers have pursued healthier lifestyles, they have to pay more attention for consumption of fruit and vegetables, encouraged by World Health Organization (WHO) recommendations and scientific data showing health benefits from these food products. Indeed, many epidemiologic studies have shown a role of diet rich in fruits and vegetables diet in the prevention of several chronic diseases, such as obesity, cardiovascular diseases and other [1–4].

Strawberries are considered as one of the most delicatessen fruits, with desirable taste value [5]. They are characterized by valuable composition, including a high content of vitamin C, but also unsaturated fatty acids and minerals (i.a. Mn, K). Besides these nutritive components, these fruits contain many of non-nutritive compounds, such as dietary fiber, flavonoids or phenolic acids. Many of these compounds exert relevant antioxidant capacities in vitro and in vivo. Among these phytochemicals, anthocyanin and ellagitannins are the major antioxidant compounds [6]. Strawberries represent a healthy food choice in our daily diet. Frozen strawberries have a special attention, because freezing is one of the most successful methods for the long-term preservation of the natural quality attributes of perishable foods [7]. Therefore, these fruits could be a valuable component of frozen dessert. It is to emphasize that freezing and storage cause several changes in chemical composition and organoleptic properties [8–10]. According to Oszmiański et al. [8] phenolic compounds, i.e., pelargonidin undergo destruction during freezing. Poiana et al. [9] confirmed the decrease in antioxidant (vitamin C, phenolic compounds) content and activity after long-term frozen storage of strawberry.

Ice cream and frozen desserts are popular throughout the world. Nowadays, the energy value of the ice cream becomes one of the most important factors determining consumer choice. In the market, there are several new products of this kind, including low-calorie or low-fat ones. Among them, frozen fruit desserts deserve special attention. Sorbet, water ice cream, is a fat-free product produced on the basis on fruits or fruit juice [11]. In the opposite to the traditional ice creams, sorbets do not also contain milk constituents, what is particularly important for people suffering from food allergies or intolerance [12]. Due to the growing consumer interest in functional food, sorbets containing fructans may be a desirable alternative to traditional ice cream desserts.

Fructans, storage carbohydrates with beta-fructofuranosyl linkages, are found in approximately 15 % of higher plants [13]. They are the main reserve carbohydrates in *Asteraceae* and in many other economically important families [14]. Fructans are a very good example of compounds with proven beneficial effect on the organism [15–20], as well as positive impact on the organoleptic attributes [21]. According to Lum and Albrecht [22], fructan presence in the product is thus valuable, not only from nutritional, but also technological point of view. Inulin-type fructans lower the freezing point in frozen desserts, but also balance the sweetness profile. These compounds can be used as to create products with different properties, because they improve the taste and texture and allow the replacement of sugar and fat [23, 24].

Commercial inulin preparations are mainly made from chicory (*Cichorium intybus* L.). However, products of other fructan-containing plants, such as Jerusalem artichoke (*Helianthus tuberosus* L.), become increasingly interesting for application in food as they do not contain bitter taste compounds [25]. Jerusalem artichoke is one of the primary sources for inulin in higher plants [26, 27]. The other valuable source of fructans is yacon (*Smallanthus sonchifolius* Poepp. Endl). Saccharides, especially oligofructans, form 70–80 % of their dry weight [28]. Its tuberous roots are sweet and crispy and are widely used, together with its leaves, to brew a medicinal tea. More recently, its physicochemical properties have contributed to its use in the development of food products, such as beverages [29].

Fructans properties (healthy and technological) are dependent *inter alia* on the polymerization degree [21, 30]. Inulin is the most commonly used in food industry, i.e., as the ingredients of dairy products, because of its prebiotic and also textural properties, bread, biscuits, cereal and meat products [21]. Our previous study concerned on the possible applications of these compounds (commercial inulin or fructooligosaccharide preparations, Jerusalem artichoke flour or pulp) for the production of bread and beverages confirmed their usefulness in this area [25, 31–33].

We also proved that the presence of fructans (from different source) affects the organoleptic properties of sorbets and it is acceptable by the consumers [34, 35].

Because of the fact that fructans stability depends on environmental conditions (i.e., temperature, pH), the aim of the study was to assess quantitative fructan (from Jerusalem artichoke tubers, yacon root as well as Beneo Orafti Synergy 1 powder) changes in strawberry sorbets, as well as glucose, fructose and sucrose content in 2-week intervals, during 3 months of storage at -22 ± 1 °C. The sorbets with the highest share of each fructan sources being acceptable by consumers were used in this study. The attempt to incorporate to the sorbet formulation as high as possible (accepted) amount of fructan is particularly important from nutritional point of view (high dose of fructan, small portion of product). To the best of authors' knowledge, no similar paper in this area has been published before.

Materials and methods

Materials

Research materials were strawberry sorbets containing three fructan sources, i.e., Jerusalem artichoke tubers (*Helinathus tuberosus* L.), yacon root powder (*Smallanthus sonchifolius*) and Beneo Orafti Synergy 1 (commercially available fructan powder). Jerusalem artichoke, var. Albik, tubers were cultivated in small agricultural holding using sustainable system of plant production (Wielkopolska Region, Poland) and harvested in the autumn (because of higher fructan content in this season). The tubers were characterized by clavate shape and white color of pulp. Organic yacon root powder was derived from Oxapampa, Peru (EverTrust, United Kingdom). According to the producer declaration, the following stages selecting, cleaning, washing and organic disinfection, peeling, slicing, airing, drying, milling and packing were used in powder production. Synergy 1, Beneo Orafti Company (Belgium) is a combination of longer- and shorter-chain inulin (certified fructan content—90.5 g/100 g d.m.). Strawberries (*Fragaria* × *ananassa* Duchesne) var. Senga Sengana (Oerlemans Foods, Poland) were obtained from market in Krakow (Poland).

Sorbets recipe and production

The preliminary studies concerned of the recipe formulation of sorbets, with different amounts of fructan sources (in the range of 0–6 % fructan content) as well as frozen strawberry fruits (share: 50 or 60 %) were done. At first,

Table 1 Recipes of sorbets (g/100 g)

Ingredient	Sorbets with		
	Jerusalem artichoke	Yacon	Beneo Orafti Synergy 1
Strawberry[a]	50.0	50.0	50.0
Fructan source[b]	34.0	16.0	6.5
Sugar	13.7	7.3	15.7
Water	2.3	26.7	27.8

[a] Dry matter content: 7.9 g/100 g; fructan content: 0.07 g/100 g

[b] Jerusalem artichoke: dry matter content 24.7 g/100 g, fructan content 14.3 g/100 g

Yacon root powder: dry matter content 24.7 g/100 g, fructan content 37.8 g/100 g

Beneo Orafti Synergy 1: dry matter content 97.2 g/100 g, fructan content: 90.5 g/100 g dm

microbiological quality of product was assessed [34]. Taking into consideration the results concerned on organoleptic analysis [35, 36], strawberry (50 % share) sorbets with maximum acceptable amount of Jerusalem artichoke, yacon, and Beneo Orafti Synergy 1 were chosen.

The production of samples (1 kg each) was done in duplicate. Prior to recipe formulation, the content of dry matter of raw materials was determined [37]. To provide the extract (total solids) on the level of 26 % appropriate amount of sugar (Cukier biały—Polski Cukier, Krakowska Spółka Cukrowa, Poland—purchased from local market in Krakow, Poland) was added. The formulations are presented in Table 1. The production of the sorbets was proceeded as follows: fruits (after defrosting in refrigerator at 4 ± 1 °C for ca. 1 h) were crushed by a universal multifunctional machine (type Zelmer 175.5), mixed with appropriate fructan sources, sugar and water, and stored for 0.5 h at 4 ± 1 °C in covered container (maturation of sorbet mixture). Then, the mixture was freezed using Frezer Mirkoz (Hungary) type MHFU/5A. Next, the sorbet containers were transferred to a freezer. The fructan stability as glucose, fructose and sucrose content in strawberry sorbets was analyzed immediately after product preparation, as well as during 3-month storage at −22 ± 2 °C, in the 2-week intervals. The analyses were conducted in the laboratory of Department of Food Technology and Nutrition, Faculty of Food Technology, University of Agriculture in Krakow.

Determination of fructan content in raw materials and sorbets

All reagents were of analytical purity grade. The analyses of fructan contents were performed according to "Fructan assay procedure or the measurement of fructooligosaccharides (FOS) and fructan polysaccharide K-FRUC" (available at https://secure.megazyme.com/Fructan-Assay-Kit), using in the step "Fructan Extraction" the sample amounts as follows:

- 100 mg of the sample (pulp of Jerusalem artichoke, yacon root powder) sample was weighed into a beaker (100 mL capacity). Then, 40 mL of hot distilled water (~80 °C) was added. The beaker was stirred with heating (at ~80 °C) for 15 min. Next, the solution was cooled to room temperature and quantitatively transferred to a 50-mL volumetric flask, adjusted with distilled water and mix thoroughly.
- 1.0 g of each sorbet sample as well as strawberry was used to the analysis and was placed into a beaker (200 mL capacity). Then, 80 mL of hot distilled water (~80 °C) was added. The beaker was stirred with heating (at ~80 °C) for 15 min. Next, the solution was cooled to room temperature and quantitatively transferred to a 100-mL volumetric flask, adjusted with distilled water and mix thoroughly. The analyses were performed using K-FRUC Kit (Megazyme International Ireland Ltd., Ireland), with spectrometer Cary 50 Bio UV–VIS (Varian, Australia). As the part of the quality control of the method, analyses of the reference material with closely defined contents of fructan were applied (Megazyme). Among other factors, reproducibility and recover factor were tested. The calculations were done by using the Megazyme Mega-CalcTM, downloaded from the Megazyme website (https://secure.megazyme.com/Fructan-Assay-Kit).

Determination of glucose, fructose, sucrose content in raw materials and sorbets

All reagents were of analytical purity grade. "Sucrose, D-Fructose and D-Glucose Assay Procedure" by Megazyme (available at https://secure.megazyme.com/Sucrose-Fructose-D-Glucose-Assay-Kit) was used to determine the content of these carbohydrates in studied samples. The pH of the solution had to be increased to approx. 7.6 using 2 M NaOH, and the solution was incubated at room temperature for 30 min.

For the determination of D-glucose, D-fructose and sucrose in sorbet samples, each of them (approx. 10 g) was homogenized in a mixer (IKA-ULTRA TURRAX homogenizer). Next, 0.5 g of the sample was weighed into a 100-mL volumetric flask, mixed with 50 mL of distilled water to dissolve, made up to the mark (with distilled water), mixed and filtered. The first 5 mL of the filtrate was discarded. The analyses were performed using K-SUFRG Kit (Megazyme International Ireland Ltd., Ireland), with spectrometer Cary 50 Bio UV–VIS (Varian, Australia). The calculations were done by using the Megazyme Mega-CalcTM downloaded from Megazyme website (https://secure.megazyme.com/Sucrose-Fructose-D-Glucose-Assay-Kit).

Reagents and chemicals

K-SUFRG Kit and K-FRUC Kit were supplied by Megazyme International Ireland Ltd. (Ireland). Maleic acid (cat. no. M-0375), PABAH (p-hydroxybenzoic acid hydrazide) (cat. no. H-9882) and sodium borohydride (cat. no. S-9125), trisodium citrate dehydrate (cat. no. S1804), calcium chloride dehydrate (cat. no. C3306) were obtained from Sigma. Other general-use laboratory reagents (NaOH, CH_3COOH) were of analytical grade and purchased from PoCH (Poland).

Statistical analyses

All the analyses were performed in triplicate. Mean values (X_{mean}) and standard deviations (SD) were calculated. The results of fructan, glucose, fructose and sucrose in sorbets were presented as percentage changes in comparison with initial value (content determined immediately after preparation) taken as 100 %. To evaluate the significance of differences between mean percentage changes of studied parameters during storage two-factorial (factor 1: fructan source; factor 2: period of storage), analysis of variance was done. Statistical significance between mean values was examined by Fisher NIR test (at $p < 0.05$). Hypothesis about normal distribution was verified by Shapiro–Wilk test, and homogeneity of variance—by Levene'a test. Moreover, correlation coefficients between fructan and fructose contents were calculated. Statistical analysis was performed using Statistica v. 10.0. software.

Results and discussion

It is known that certain food additives that are used in the manufacture of food products can change their functional and other properties during storage and distribution [24]. Analysis of fructan content in raw plant materials showed that Jerusalem artichoke pulp contained these compounds in the amount of 14.3 g/100 g. The content of fructans in yacon root powder was on the level of 37.8 g/100 g. According to Van Loo et al. [38], inulin content is dependent on fructan source. Lingyun et al. [23] noted that Jerusalem artichoke (JA) tubers contained 14–19 % of inulin. Similar results (15–20 %) were presented by Kaur and Gupta [39]. Dwivedi et al. [40] presented that tubers of Jerusalem artichoke were characterized by fructans on the levels 19.4–29.2 g/100 g fresh weight and from 55.3 to 74.0 % dry weight. Study performed by Florkiewicz et al. [41], concerning on fructan content in Jerusalem artichoke tubers var. Albik, showed that the content of these compounds was 50.5 g/100 g dry matter (above 10 % in fresh matter). According to Dwivedi et al. [40], dry matter of yacon contained from 6.4 to 65.0 g of fructooligosaccharide per 100 g and from 141 to 289 mg inulin per kg. The strawberry sample was characterized by slight amounts of fructans (0.07 g/100 g fresh weight).

Table 2 Results of two-way ANOVA

Compound	Factor		
	Fructan source	Time of storage	Interactions
Fructan	$p = 0.085441$	$p = 0.000000$	$p = 0.000063$
Glucose	$p = 0.000007$	$p = 0.000000$	$p = 0.224639$
Fructose	$p = 0.000002$	$p = 0.000000$	$p = 0.000232$
Sucrose	$p = 0.000000$	$p = 0.000000$	$p = 0.000019$

The changes of fructan level in sorbets depended on the period of storage (Table 2). Immediately after production sorbet with Jerusalem artichoke tuber pulp (SJ) contained 4.31 g/100 g, sorbet with yacon root powder (SY)—5.93 g/100 g and sorbet with Beneo Orafti Synergy 1 (SS)—5.50 g/100 g (Table 3). In all products (independently from fructan source), the decrease in the fructan content was observed during whole storage period at −22 ± 2 °C (Fig. 1). After 2 weeks of storage, the amount of these compounds in sorbet with Orafti Synergy 1 (SS) was lower only about 0.12 % from the initial value ($p > 0.05$). Similar tendency was noted for two other fruit products. In the next 2 weeks, significantly higher reduction of fructan level in SJ and SS was shown, as compared to initial values. Sorbets stored for 6 or 8 weeks were characterized by 70.8–74.4 or 67.6–71.3 % of fructan content determined immediately after production, respectively. Total loss of fructans was significantly smaller in sorbet with Jerusalem artichoke tubers, in comparison with SY and SS. The lowest ($p < 0.05$) level of these carbohydrates was found in SY. At the end of the experiment, SJ contained 65.2 % of fructans determined immediately after product preparation. Thus, fructans in this sorbet were characterized by the highest stability. It could be the consequence of difference in the polymerization degree (DP) of fructan. Da Fonseca Contado et al. [42] noticed that DP of yacon fructans was between 3 and 7. Meanwhile, Rubel et al. [43] obtained higher DP values for Jerusalem artichoke fructans. There are evidences that DP of fructan in JA tubers harvested in autumn is 19, meanwhile in tubers harvested in Spring is only 9 [41]. In the present study, the pulp of JA tubers from autumn harvest was used for sorbet production. It could explain better stability of these compounds in SJ. According to Mensink et al. [21] higher DP inulin fractions are less soluble in water and chemically more stable (less sensitive to hydrolysis). Lugovska et al. [24] noticed

Table 3 Initial and final (after 12 weeks of storage) contents of carbohydrates (g/100 g)

Compound	Period of storage (weeks)	Sorbets		
		SJ	SY	SS
Fructan	0	4.31	5.93	5.50
	12	2.81	3.06	2.92
Glucose	0	1.67	2.04	1.39
	12	2.06	2.71	2.06
Fructose	0	1.78	3.05	1.70
	12	2.81	3.90	2.68
Sucrose	0	12.66	14.37	16.53
	12	15.06	16.46	18.32

that in the acidic medium and high temperature, inulin and oligofructose can be hydrolyzed to form shorter chains and fructose. The pH value of sorbets was in the range 3.3–3.8, what could contribute to the carbohydrate hydrolysis. According to Glibowski and Bukowska [44], this reaction is more intensive in lower pH. These authors stated that the inulin in acidic foods, especially heated at temperature above 60 °C, is less stable. It is particularly important in our study, because the production of sorbets involved pasteurization of the raw materials (to provide microbiological safety of the product). According to Matusek et al. [45], fructooligosaccharides are liable to hydrolysis in the conditions occurring during the pasteurization of fruit juices and drinks. The amount of hydrolyzed saccharides is greater the lower the pH and the longer the heat effect. The degree of hydrolysis of FOS can even reach the value of over 80 %.

Simultaneously performed analyses of reducing sugars (glucose, fructose) and sucrose content showed the opposite tendency during storage. It is important because the content of these compounds may influence on sensory quality of the products and consumer acceptance. Initial level of glucose and fructose in sorbet with Beneo Orafti Synergy 1 was 1.39 and 1.70 g/100 g, in SY sorbet: glucose—2.04 g/100 g; fructose—3.05 g/100 g and in SJ sorbet: glucose—1.67 g/100 g; fructose—1.78 g/100 g (Table 3). In the case of SJ and SY, significant increase in the glucose level (as compared to the initial value) was not observed until 6 weeks of storage, whereas in SS it was noticed after 2 weeks (Fig. 2). The fructose level in sorbet containing yacon root powder increased significantly (in relation to initial amount) after 6 weeks (Fig. 3). The content of this carbohydrate in SJ and SS was higher ($p < 0.05$) after 8 and 2 weeks of storage, respectively. The results of analyses performed after 12 weeks of the storage showed that the changes of fructose content in sorbet with Beneo Orafti Synergy 1 and also with pulp from Jerusalem artichoke tubers were similar ($p > 0.05$), i.e., an increase of 57 % compared to initial value was observed. Meanwhile, sorbet with yacon root powder contained 28 % higher amount of fructose at the end of storage than the product immediately after preparation. Negative correlation between fructan and fructose content in our study was observed (SJ: −0.79; SY: −0.91 and SS: −0.93). The

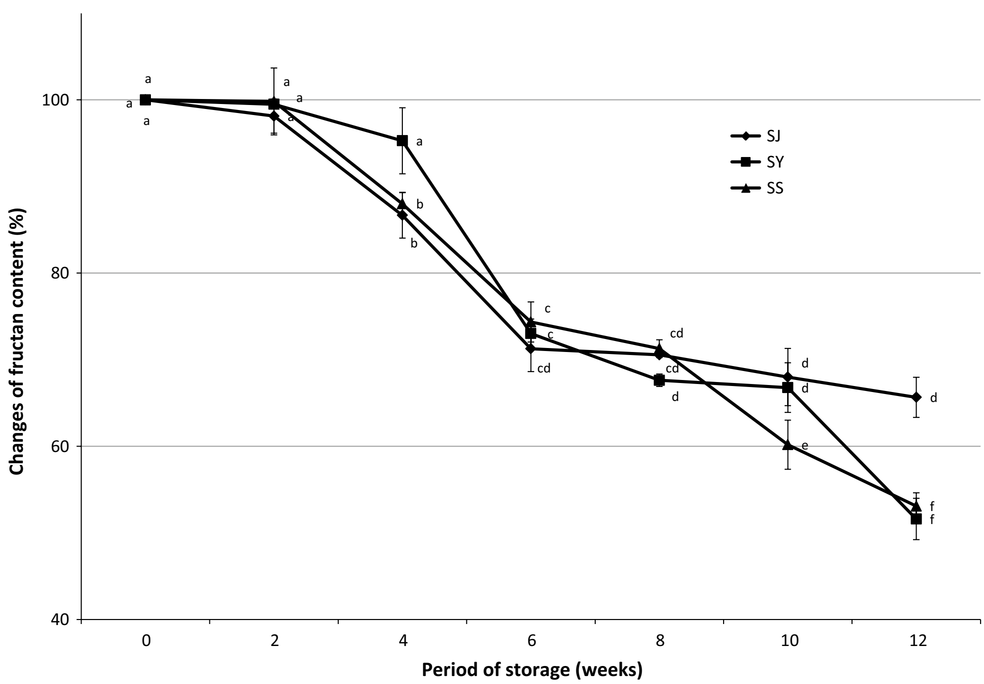

Fig. 1 Changes of fructan content in strawberry sorbets in dependence on their source and storage period

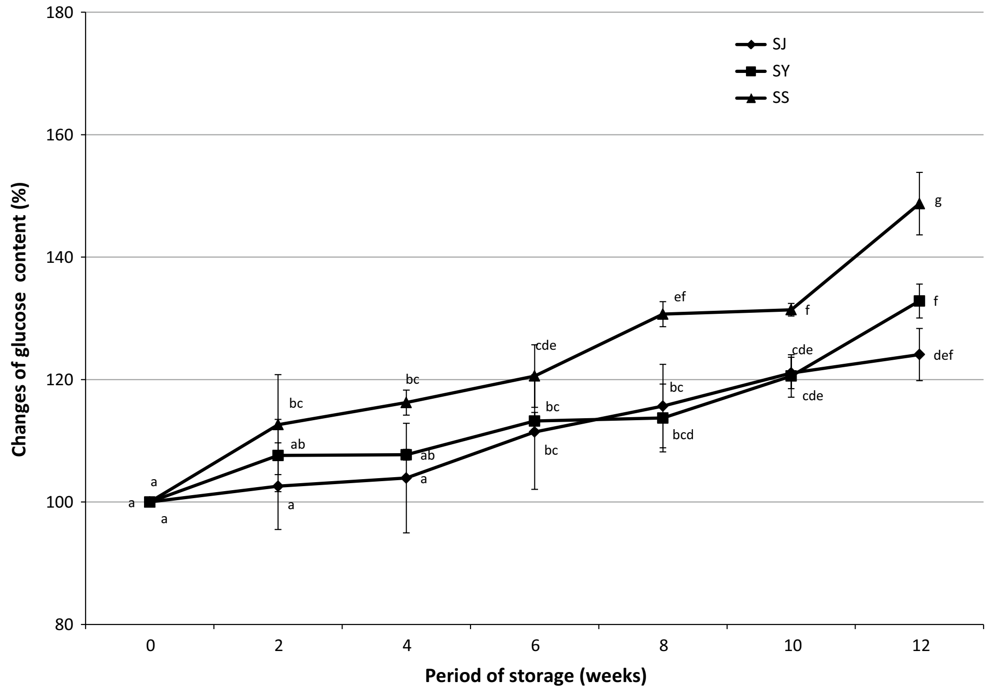

Fig. 2 Changes of glucose content in strawberry sorbets in dependence on fructan source and storage period

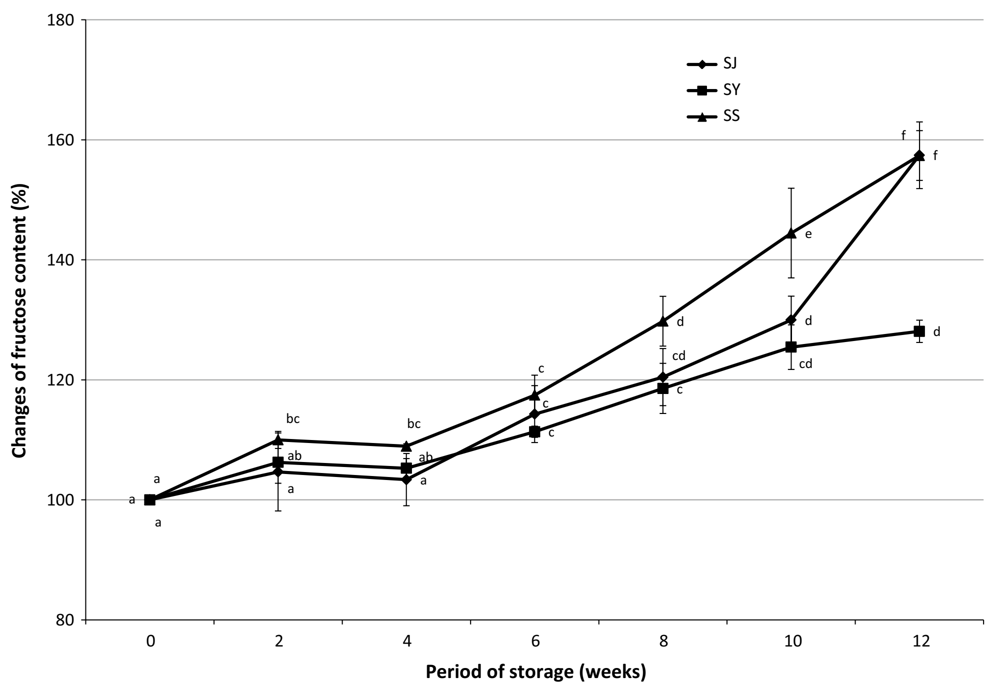

Fig. 3 Changes of fructose content in strawberry sorbets in dependence on fructan source and storage period

similar dependance ($r = -0.88$) in yacon root was noted by Hermann et al. [46]. It indicates the interrelation of these carbohydrates in depolymerization. According to Lachman et al. [28], changes of yacon tubers oligosaccharides during storage have been of great importance. Decreasing levels of inulin and in contrary enhancing contents of fructose and glucose confirm the hydrolyzing process during yacon storage. Increasing of fructose and glucose

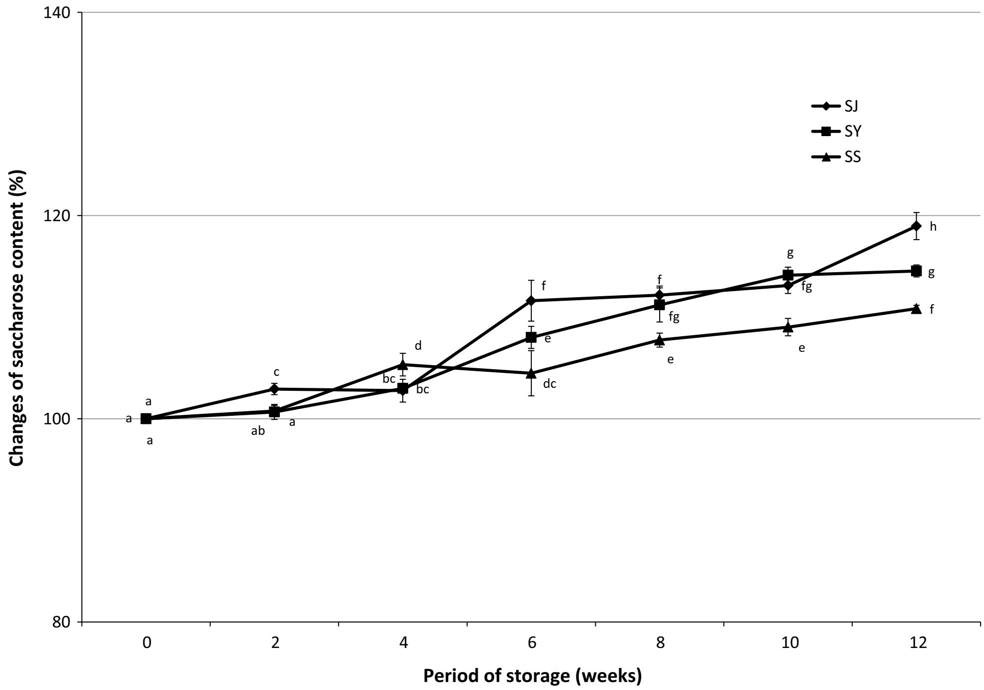

Fig. 4 Changes of sucrose content in strawberry sorbets in dependence on fructan source and storage period

content in Jerusalem artichoke tubers during storage was also observed [41, 47].

The sorbets SJ, SY and SS after preparation were characterized by sucrose content on the level of 12.66, 14.37 and 16.53 g/100 g, respectively (Table 3). These results were the consequence of higher share of sugar in the recipe. After 3 months of freezing storage, the content of sucrose in sorbets increased by 10–18 % (Fig. 4). Despite the smallest change between initial and final sucrose contents in SS, this product was still characterized by the highest amount of this compound. It could be disadvantageous from nutritional point of view.

Further investigations to minimize fructan losses in frozen fruit dessert as well as establish optimal freezing storage conditions are needed. It could allow offering the product of the best quality (with the highest content of pro-healthy compounds) for the consumer.

Conclusion

1. It was observed that the losses of the fructan content were insignificant during the first 2 weeks of storage in all sorbets.
2. The decrease in fructan content was connected with the enhancement in glucose, fructose as well as sucrose level, independently of fructan source.
3. Sorbet with Jerusalem artichoke tubers was characterized by the highest stability of fructans, as compared to the other products, after 12 weeks of freezing storage.

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Compliance with ethical standards

Conflict of interest The Authors declare no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with animal or human subjects.

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